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12. ABSTRACT (Maximum 200 words)

The Symposium took place at the Abdus Salam International Centre for Theoretical Physics, Trieste, Italy from 3-5 July 2000. The two main thrusts were: (1) synchronization of systems of small numbers of elements, often two, such as lasers and circuits with applications to communications and (2) ordering, synchronization and clustering in systems of large populations of elements with applications in biology and chemistry.

This report consists of a symposium summary, participant list and the program with short abstracts.

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the
abdus salam
international centre for theoretical physics

SYMPOSIUM ON SYNCHRONIZATION OF CHAOTIC SYSTEMS
3 - 5 July 2000

Co-sponsored by the US Office of Naval Research and ONRIFO (Office of Naval Research International Field Office, Europe)

FINAL REPORT

The Symposium, held in memory of Professor Stig Lundqvist, took place at the Abdus Salam International Centre for Theoretical Physics, Trieste, Italy, from 3 to 5 July 2000. It dealt with several characteristics of chaotic synchronization.

The purpose of this meeting was to accomplish close collaboration between experimental and theoretical groups, enhance the exchange of information and ideas and to promote the understanding of the phenomena that lead to the synchronization of highly chaotic systems.

Several important subjects were discussed from the theoretical simulation and experimental perspectives. Many of the contributions fell into two thrust areas : (1) synchronization of systems of small numbers of elements, often two, such as lasers and circuits with applications to communications and (2) ordering, synchronization and clustering in systems of large populations of elements with applications in biology and chemistry. In the first group were contributions related to a fundamental understanding of synchronization, data compression using chaotic algorithms, estimation of error in synchronization using information theoretical techniques, chaotic electronics in telecommunications, and synchronization of lasers and high dimensional chaotic signals. In the second group were contributions to globally coupled systems as models to study biological systems, phase synchronization as a way to study neuronal activity, and theoretical and experimental studies of clustering and organization in large groups of elements with examples in biology and chemistry.

The Symposium showed that the field of synchronization of chaotic systems has grown into a full area of research, which stands on its own with many open problems.

The Conference was attended by 82 participants. It was partially supported by the U.S. Office of Naval Research and ONRIFO (Office of Naval Research International Field Office, Europe).

The programme and list of participants of the conference are enclosed.

Tom Carroll | Hilda Cerdeira | Jack Hudson | Lou Pecora

The Organizers

united nations educational, scientific and cultural organization

international atomic energy agency

the
abdus salam
international centre for theoretical physics

SYMPOSIUM ON SYNCHRONIZATION OF CHAOTIC SYSTEMS

3 - 5 July 2000

Co-sponsored by the US Office of Naval Research and ONRIFO (Office of Naval Research International Field Office, Europe)

IN MEMORY OF STIG LUNDQVIST

FINAL PROGRAMME

VENUE : Lecture Room C, O (Terrace) Level, Main Building

Monday, 3 July

08:00 - 10:20 **REGISTRATION**

10:20 - 10:30 **Opening Ceremony - Hilda Cerdeira - Abdus Salam ICTP, Trieste, Italy**

SESSION CHAIR - Jack HUDSON - University of Virginia, Charlottesville, USA

10:30 - 11:10 **Hirokazu Fujisaka - Kyoto University, Japan**
"On-off intermittency in spatially distributed dynamical systems"

11:10 - 11:50 **Alexander S. Mikhailov - Fritz-Haber-Institut, Berlin, Germany**
"Globally coupled logistic maps as dynamical glasses"

11:50 - 12:30 **Kunihiko Kaneko - University of Tokyo, Japan**
"From coupled dynamical systems to developmental cell biology"

12:30 - 14:30 **LUNCH**

SESSION CHAIR - Lou PECORA - Naval Research Laboratory, Washington, USA

14:30 - 15:10 **Valentin Afraimovich - University of San Luis de Potosi,Mexico**
"Poincare recurrences in synchronized regimes"

15:10 - 15:50 **Tito Arecchi - University of Florence, Italy**
"Synchronization of homoclinic chaos"

15:50 - 16:30 **Martin Hasler - Federal Institute of Technology, Lausanne, Switzerland**
"Information theoretic view of chaos synchronization"

16:30 - 17:00 **BREAK**

SESSION CHAIR - Hilda CERDEIRA - Abdus Salam ICTP, Trieste, Italy

17:00 - 17:20 **Murilo da Silva Baptista - University of São Paulo, Brazil**
"Integrated chaotic communication scheme"

17:20 - 17:40 **Krishnamurthy Murali - Anna University, Chennai, India**
"Synchronization based signal transmission applications with heterogeneous chaotic signals"

17:40 - 18:00 **Raul Toral - IMEDEA, Palma de de Mallorca, Spain**
"Coherence resonance in chaotic systems"

18:30 **SMALL RECEPTION - TERRACE LEVEL, MAIN BUILDING**

Tuesday, 4 July

SESSION CHAIR - **Tom CARROLL -- Naval Research Laboratory, Washington, USA**

09:00 - 09:40	**Jurgen Kurths - University of Potsdam, Germany** "Inferring phase synchronization from multivariate data"
09:40 - 10:20	**Ulrich Parlitz - University of Göttingen, Germany** "Dynamic coupling, chaotic lasers and phase synchronization of Ginzburg Landau equations"
10:20 - 11:00	**COFFEE BREAK**
11:00	**Please Note - MAIN LECTURE HALL, Main Building.** **Martinus J.G. VELTMAN - 1999 Nobel Laureate** **DIRAC MEDAL AWARD CEREMONY &** **LECTURE - "Cancelling infinities"**
12:10 - 14:30	**LUNCH**

SESSION CHAIR - **Kunihiko KANEKO - University of Tokyo, Japan**

14:30 - 15:10	**Kestutis Pyragas - Semiconductor Physics Institute, Vilnius, Lithuania** "Generalized synchronization of chaos"
15:10 - 15:50	**Mikhail Suschik - University of California, San Diego, USA** "Decreasing detection and intercept probability of RF communications by using chaos"
15:50 - 16:30	**Istvan Kiss - University of Debrecen, Hungary** "Synchronization and clustering in a globally coupled chaotic electrochemical system"
16:30 - 17:00	**BREAK**

SESSION CHAIR - **Hu GANG - Beijing Normal University, Beijing, China**

17:00 - 17:20	**Jose Rios Leite - Federal University of Pernambuco, Recife, Brazil** "Synchronization of chaotic lasers"
17:20 - 17:40	**Sudeshna Sinha - Institute of Mathematical Sciences, Chennai, India** "Asynchronous updating of coupled maps leads to synchronisation"
17:40 - 18:00	**Damian H. Zanette - Centro Atomico Bariloche, Bariloche, Argentina** "Learning how to synchronize"

Wednesday, 5 July

SESSION CHAIR - Alexander MIKHAILOV -- Fritz-Haber-Institut, Berlin, Germany USA

09:00 - 09:40	**Nikolai Rulkov- University of California, San Diego, USA** "Chaos regularization in synchronized chaotic oscillators"
09:40 - 10:20	**Wolfgang Schwarz - Technical University, Dresden, Germany** "Chaotic synchronization for information encryption"
10:20 - 10:50	**COFFEE BREAK**

SESSION CHAIR - Hirokazu FUJISAKA - Kyoto University, Japan

10:50 - 11:30	**Michael P. Kennedy - University College, Dublin, Ireland** "The role of synchronization in digital communications using chaos"
11:30 - 11:50	**Neelima Gupte - Indian Institute of Technology, Chennai, India** "Bifurcations from synchronized solutions in coupled sine circle map lattices "
11:50 - 12:10	**Mauricio Barahona - California Institute of Technology, Pasadena, USA** "Synchronization of small-world chaotic networks"
12:10 - 14:30	**LUNCH**
14:30 - 15:30	**POSTER SESSION**

SESSION CHAIR - Tito ARECCHI - University of Florence, Italy

15:30 - 16:10	**Maciej Ogorzalek - University of Mining,Crakow, Poland** "Chaos-based signal processing"
16:10 - 16:50	**Stefano Boccaletti - University of Navarra, Pamplona, Spain** "A unifying framework for synchronization of coupled dynamical system"
16:50 - 17:30	**Hu Gang - Beijing Normal University, Beijing, China** "From low dimensional chaos to high dimensional chaos: Variations of synchronization and spatial symmetries in coupled chaotic oscillators"
17:30	**CLOSING CEREMONY - Tito ARRECHI - University of Florence, Italy**

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SYMPOSIUM ON SYNCHRONIZATION OF CHAOTIC SYSTEMS

3 July 2000 - 5 July 2000

FINAL LIST OF PARTICIPANTS

Total number of visitors for this activity = 82

Co-sponsored by the US Office of Naval Research and ONRIFO
(Office of Naval Research International Field Office, Europe)

Updated: 6 July, 2000

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ABSTRACTS

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Poincare Recurrences in Synchronized Regimes

V. Afraimovich
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The mathematical study of chaotic synchronization is often based upon the analysis of the existence and properties of an invariant manifold containing orbits corresponding to synchronized regimes. In the talk we discuss a new approach that uses the notions of topological synchronization and the dimension for Poincare recurrences. We show that the dimension for Poincare recurrences may serve as an indicator for the existence of synchronized regimes.

Synchronization of Homoclinic Chaos

F.T. Arecchi
University of Florence and Istituto Nazionale di Ottica Applicata, Italy

Homoclinic chaos is characterized by regular geometric orbits occurring at erratic times. The most suitable indicator to be extracted from an experimental time series is the interspike interval (ISI). A chaos control based upon the sequence of ISI's would not be reliable, since successive spikes are very weakly correlated. However synchronization at the average repetition frequency is easily realized by a tiny perturbation of a control parameter. The size of the corresponding Arnold tongue shows that this synchronization is very robust against mismatches of the modulation frequency. Furthermore, satellite synchronization regimes can be realized with variable numbers of homoclinic spikes per period of the modulation.
An experiment has been carried on a CO-2 laser with feedback, and we find a good agreement between the laboratory data and the theory.

Integrated Chaotic Communication Scheme

Murilo S. Baptista
Universidade de São Paulo, Brazil

We present the characteristics and the analysis of a proposed new communication scheme fully based on chaos theory. The key point is that the proposed scheme introduces the dynamical system as a way to encode/decode information and as a signal wave generator. In this new scheme, all the protocols used to communicate digitally are fully integrated into one single design based on a chaotic modulation process. The chaotic encoder finds a set of trajectories that codes the information into a hard to decode chaotic waveform that carries a large amount of information. We also show how our scheme can handle multiplexing, which is also used as a way to enhance security, and its ability to handle noise.

Synchronization of Small-World Chaotic Networks

Mauricio Barahona
California Institute of Technology, Pasadena, U.S.A.

The addition of random long-range connections (shortcuts) to a locally regular graph turns it into a small-world: a network which still has a local cliquish structure but with much more compact global properties. An important example of the dynamical implications of the small-world effect is the improved synchronization of chaotic systems through the addition of shortcuts to regular networks. In this talk, we present numerical and analytical work to quantify how the addition of long-range connections increases the synchronizability region of the array.

(Work done in collaboration with Steven Strogatz and Lou Pecora)

A Unifying Framework for Synchronization of Coupled Dynamical System

S. Boccaletti (1), Louis M. Pecora (2), H. Mancini (1) and A. Pelaez (1)
(1) Universidad de Navarra, Pamplona, Spain
(2) Naval Research Laboratory, Washington, U.S.A.

A definition of synchronization of coupled dynamical systems is provided. We discuss how such a definition allows one to identify a unifying framework for synchronization of dynamical systems, which encompasses all different phenomena described so far in the context of synchronization of chaotic systems.

On-Off Intermittency In Spatially Distributed Dynamical Systems

Hirokazu Fujisaka
Kyoto University, Japan

On-off intermittency is a characteristic phenomenon observed when a particular chaotic motion such as the synchronized chaos in coupled chaotic systems undergoes the instablity as the control parameter is changed. In my talk I will address the possibility of the observation of the intermittency for physcial systems observed in association with, e.g., spin wave instability and the electrohydrodynamic convection in nematic liquid crystals. Using mathematical models I will discuss intermittent excitation corresponding to spin waves and the intermittent onset of convection. Furthermore I will compare their statistical characteristics numerically observed with those of on-off intermittency known so far.

Synchronization, Symmetry Breaking, and Patterns in Coupled Chaotic Systems.

Gang Hu{1,2}, Ying Zhang{3}, Hilda A. Cerdeira{4}, and Shigang Chen{3}

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Dynamic behavior of coupled chaotic oscillators is investigated. For small coupling, chaotic state undergoes a transition from spatially disordered phase to ordered phase with an orientation symmetry breaking. For large coupling a transition from full synchronization to partial synchronization with translation symmetry breaking is observed. Two bifurcation branches, one inphase branch starting from synchronous chaos and the other antiphase branch bifurcated from spatially random chaos, are identified by varying coupling strength. Hysteresis, bistability and first-order-transitions between these two branches are observed.

Bifurcations from Synchronized Solutions in Coupled Sine Circle Map Lattices

Neelima Gupte
Indian Institute of Technology, Chennai, India

We discuss bifurcations from synchronised solutions in coupled sine circle map lattice systems. Spatially periodic initial conditions settle down to synchronised solutions, travelling wave solutions and frozen spatial period two solutions in regions which correspond to the 0/1 and 1/1 tongues of the single circle maps. Spatio-temporal bifurcations are seen between these solutions. We set up the characterisers of these bifurcations and discuss their behaviour. Kink initial conditions settle down to frozen kink solutions and kink induced intermittent solutions in the same regions of parameter space. Bifurcations from synchronised solutions to these solutions show severalinteresting features. We discuss these features and set up new quantifiers for these bifurcations and compare them with the quantifiers for the periodic solutions.

Information Theoretic View of Chaos Synchronization

M. Hasler
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When chaos synchronization is applied to the transmission of information, the receiver has to be synchronized with the transmitter. However, the transmitted chaotic signal that allows to achieve synchronization is corrupted by noise. This is the classical application area of information theory. We therefore compare the performance of synchronization in the presence of noise with the limit given by information theory and explore how this performance could be improved.

From Coupled Dynamical Systems to Developmental Cell Biology

Kunihiko Kaneko
University of Tokyo, Japan

Some studies in coupled dynamical systems are briefly surveyed, focusing on strength of attractors, noise-induced selection of Milnor attractors, and chaotic itinerancy. Then, developmental process of cells is discussed, based on several studies of dynamical systems with internal degrees of freedom, interaction, and reproduction. Differentiation of cells, formation of discrete and recursive cell types, and emergence of stem cells, and differentiation rules to attain the developmental robustness are shown to be a natural consequence of such system. Irreversibility in biological development is discussed in terms of dynamical systems.

The Role of Synchronization in Digital Communications Using Chaos

<u>Michael Peter Kennedy</u>{1} and Geza Kolumban{2}
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Over the past five years, much research effort has been devoted to the study of digital modulation schemes using chaotic basis functions. It is now possible to make definitive statements about the noise performance of these schemes. The aim of this tutorial is to present theoretical performance bounds for chaotic digital modulation schemes, to summarize the performance of some representative schemes relative to these limits, and to highlight expected best case performance in practice.

Synchronization and Clustering in a Globally Coupled Chaotic Electrochemical System

Istvan Z. Kiss{1,2}, Wen Wang{1} and John L. Hudson{1}
1) University of Virginia, Charlottesville, U.S.A.
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We present experimental results of a chemically reacting system (electrodissolution of Ni in sulfuric acid solution) made up of 64 low-dimensional chaotic individual elements to which global coupling is added. The addition of global coupling transforms a system of independent elements to a state of complete synchronization. Clustering occurred at intermediate values of the coupling strength. Many cluster configurations occur under the same conditions and transitions among them can be produced. For values of the coupling parameter on either side of the stable cluster region a non-stationary behavior occurs in which clustered and synchronized states alternatively form and break up. Some statistical properties of the cluster states are determined.

Inferring Phase Synchronization from Multivariate Data

J. Kurths{1}, M. Rosenblum{1}, A. Pikovsky{1} and P. Tass{2}
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We use the concept of phase synchronization for the analysis of noisy nonstationary bivariate data. Phase synchronization is understood in a statistical sense as an existence of preferred values of the phase difference. Two techniques are proposed for quantification of phase locking. These methods are applied to multichannel magnetoencephalograms and records of muscle activity of a Parkinsonian patient and to the solar activity and solar inertial motion. We show that our techniques allow to detect epochs of phase synchronized regimes in such noisy data.

Globally Coupled Logistic Maps as Dynamical Glasses

Susanna C. Manrubia and **Alexander S. Mikhailov**
Fritz-Haber-Institut der Max.Planck-Gesellschaft, Berlin, Germany

We define replicas and compute distributions of overlaps between them in a large dynamical system formed by globally coupled logistic maps under partial synchronization conditions. Our analysis indicates that the replica symmetry is broken here and the system behaves as a dynamical spin glass.
Further on, we by computing and analyzing the three-replica overlap distributions, the ultrametric hierarchical organization of attractors in this system is tested.

Synchronization Based Signal Transmission Applications with Heterogeneous Chaotic Systems

K. Murali
Anna University, Chennai, INDIA

A new chaos based secure communication system is proposed to transmit information signals by using the conventional synchronization approach with cascaded heterogeneous chaotic systems. In this scheme, a kind of nonlinear information mixing is achieved within the transmitter-module. An appropriate feedback loop is constructed in the response-module to achieve synchronization among the variables of the drive and response modules. Simulation results are reported in which the quality of the recovered signal is higher and the encoding is potentially secure. The effect of perturbing factors like channel noise and mismatch in parameters are also considered.

Chaos-Based Signal Processing

M. J. Ogorzalek
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Given a time series measured (or generated) by a known or an unknown dynamical system we address a series of problems which can be considered as advanced signal processing tasks, namely:

-) section-wise approximation of the measured signal by pieces of trajectories from a chosen nonlinear dynamical system (model);

-)signal restoration when the measured signal has been corrupted eg. by quantization;

-) signal coding and compression.

These tasks can be addressed using a new approach to the shadowing problem based on nonlinear observability problem. Its goal is to reproduce initial conditions for a dynamical system under consideration (approximating waveform generator) giving rise to an orbit which is optimal in the sense of average distance from the measured (or prescribed) transient output waveform.

Robust Synchronization, Adaptive Coupling and Spatio-Temporal Systems

U. Parlitz
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Different aspects of robustness of chaos synchronization are discussed. It is demonstrated how to deal with noisy (coupling) signals using linear and nonlinear filters. The influence of perturbations of the coupled systems is studied in the frame work of synchronization manifolds and it is shown for identical as well as generalized synchronization that not only (strong) contraction rates are of importance to achieve robustness but also (proper) contraction directions. Focussing on expanding directions only, a new adaptive and very efficient coupling scheme is presented, which allows to synchronize two given systems with a very low information flow. Finally synchronization phenomena of spatially extended systems will discussed including identical synchronization due to sensor coupling and phase synchronization of coupled Ginzburg-Landau equations.

Generalized Synchronization of Chaos

K. Pyragas
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Generalized synchronization of chaos appears in non-identical uni-directionally coupled dynamical systems. It is characterized by a complex synchronization manifold that defines a non-trivial mapping between the variables of the driving and response systems. Depending on the coupling strength the synchronization manifold can be the smooth (strong synchronization) or the fractal (weak synchronization). A weak non-identical synchronization may occur even in coupled identical systems. Close to threshold of weak synchronization coupled chaotic system experience an on-off intermittency that is characterized by escape of trajectories from an unstable fractal synchronization manifold.

To detect and analyze generalized synchronization in xperiment various practical tools have been developed. They include an auxiliary response system, an algorithm for estimating conditional Lyapunov exponents from two scalar time series, and others.

Synchronization of Chaotic Lasers

J.R. Rios Leite and H.L.D. de S. Cavalcante
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Synchronization of coupled chaotic CO_2 lasers with saturable absorber was studied experimentally and simulations of masked communication with these lasers was done with analog circuits. The conditions for synchronism are related to the fast saturation of the absorber. The synchronizations of Haken-Lorenz laser will be discussed with results from numerical and circuits simulations.

Chaos Regularization in Synchronized Chaotic Oscillators

Nikolai Rulkov
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The interest in studies of dynamical aspects of chaos synchronization is motivated in part by possibilities of developing new tools for nonlinear analysis of regimes of cooperative behavior in coupled chaotic oscillators. The onset of synchronization always results in a qualitative change of the cooperative behavior. This paper presents a few examples where synchronization between chaotic oscillators leads to the onset of chaotic oscillations with more regular temporal behavior than the individual behaviors of each uncoupled oscillator. We discuss dynamical features of such synchronization and mechanisms responsible for chaos regularization.

Chaotic Synchronization for Information Encryption

W. Schwarz
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The lecture describes the design of an encryption system using Chaos Synchronization and inverse system technique. A top-down design starting from statistical design objectives and ending up with the system structure will be presented. The result is a self-synchronizing structure. The realization of the structure by electronic circuitry is shown, and an analysis of the system behavior is provided. Also estimates for the privacy obtained, are given.
A practical demonstration of the system is also possible.

Asynchronous Updating of Coupled Maps leads to Synchronisation

S. Sinha
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We investigate the spatiotemporal dynamics of coupled map lattices evolving under updating rules incorporating varying degrees of asynchronicity. Interestingly, we observe that parallel updates never allow synchronisation among the sites, while asynchroncity has the effect of opening up windows in parameter space where the synchronised dynamics gains stability. As asynchronicity increases, the parameter range supporting synchronisation gets rapidly wider. Detailed numerics, including bifurcation diagrams and patterns formed en route to synchronisation, is reported. We also present analytical mean-field results, which account for the stability of the synchronised fixed point under asynchronous updates.

Decreasing Detection and Intercept Probability of RF Communications by Using Chaos.

Mikhail Sushchik, Nikolai Rulkov, Lev Tsimring, Alexander Volkovskii, Kung Yao, Lawrence Larson and Henry Abarbanel
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Recent research revealed serious obstacles along the path to practical applications of chaos in communications. In an attempt to overcome some of these we look closer at the benefits of using chaotic systems within conventional designs, rather than attempting to develop a competitive scheme relying exclusively on chaos. We argue that such symbiosis can produce systems that have lower probability of detection and intercept than conventional systems at the price of a slightly lower performance in terms of bit error rate. This point is illustrated by two examples: the chaotic pulse position modulation scheme and the continuous chaotic frequency hopping.

Coherence Resonance in Chaotic Systems

Raúl Toral{1}, Claudio R. Mirasso{1}, Carlos Palenzuela{1}
and James D. Gunton{1,2}
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Although noise is usually considered as a disordering agent, it is known that there are situations in which a given amount of noise can actually lead to a better synchronization of a bistable system to an external periodic forcing. This is the mechanism of stochastic resonance that has been nowadays well established in several physical as well as biological systems. A related effect of noise, named coherence resonance, has also been found recently in excitable systems. In this case, the right amount of noise can produce a nearly periodic movement in which the normalized variance of the times between successive excitable pulses is minimized. In this work, we show that it is possible to have coherence resonance in non-excitable systems with a periodic or chaotic intrinsic dynamics.

Learning How to Synchronize

Luis G. Moyano, Guillermo Abramson and **D.H. Zanette**
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As a form of collective behaviour, synchronization can be observed at several levels in biological populations. This suggests that synchronization could be either selected by evolution or learnt through some specific mechanism.

We present a model of globally coupled chaotic maps added with a learning process, which is aimed at reaching a fully synchronized state from an initial condition in the incoherent phase. Learning acts by changing the coupling constant of each element, and is characterized by a parameter that measures how strict learning is. As a function of this parameter, the system shows a sharp transition from a phase where learning does occur to a phase where learning is impossible. This behaviour is driven by the intermittent dynamics of maps just bellow the synchronization threshold.

In the learning phase, the learning time reaches a minimum at an intermediate value of the relevant parameter, where the learning conditions are neither too loose nor too severe.

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Rate of Information Transmitted by Communication with Dynamical Systems

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"We demonstrate a formula which shows the rate of information per seconds that a 3D dynamical system is able to transmit, depending on the values of the Lyapunov exponents, the fractal dimension of the system, the frequency of the channel, the average frequency of the dynamical system, the level of noise present in the channel, and the precision with which we define the chaotic orbits. This formula is the basis of a new theory of communication which integrates all the protocols used in standard digital communication systems into a single chaotic modulation process."

Beyond Generalized Synchrony: Topological Decoherence and Emergent Sets in Coupled Chaotic Systems

Ernest Barreto, Paul So, Bruce J. Gluckman, and Steven J. Schiff
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We consider the evolution of the unstable periodic orbit structure of coupled chaotic systems. This involves the creation of a complicated set outside of the synchronization manifold (the emergent set). We quantitatively identify a critical transition point in its development (the decoherence transition). For asymmetric systems we also describe a migration of unstable periodic orbits that is of central importance in understanding these systems. Our framework provides an experimentally measurable transition, even in situations where previously described bifurcation structures are inapplicable.

Non-linear Synchronization of Chromospheric Oscillations

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We apply different nonlinear techniques to the intensity oscillations of the chromospheric bright points observed at the Vacuum Tower Telescope (VTT) of the Sacramento Peak Observatory, a 35-min time sequence spectra in the CaII H line over a quiet region at the center of the solar disk under high spatial, spectral, and temporal resolution. We find from the periodicity analysis that most of the bright points are composed of two non-sinusoidal periodic components with different periodicity varies from 2.6 min to 5.8 min. In addition, by using the spatial embedding technique, the correlation integral was found to be significantly different from the multivariate surrogates.
Moreover, two different methods of finding interdependencies between two two systems - dynamical phase synchronization and the similarity index- have been employed and the results are coompared with multivariate surrogate data. A novel network scheme is proposed prescribing the type of interaction between different bright points.

Synchronization Patterns in Rössler like Oscillators

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We investigate experimental and numerically the occurrence of synchronization patterns in six coupled Rössler-like oscillators. They are arranged in a ring where each oscillator is coupled to its neighbors. The control parameter is the coupling strength and according to its value some of the oscillators may synchronize establishing a synchronization pattern.

Phase Ordering and Synchronization in Globally Coupled Multistable Systems

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The phase-ordering properties of globally coupled multistable chaotic maps is investiged. The collective dynamics of the network is characterized by the persistence probability which shows a first order phase transition at some critical value of the coupling parameter. This transition precedes the onset of synchronization in the system.

Brain-like Chaos-Period Transitions in Driven Chua's Circuit

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When Chua's circuit is driven by either sinusoidal oscillation or periodic pulses, it generates choas-period transition patterns. The occurrence of such pattern depends upon the frequency and amplitude of the driving signal. The frequency has been uniquely idenfied as the third harmonics of the driving signal frequency. The amplitude has been idenfied by trial and error. This phenomena has a general effect on chaotic system like Lorenz system also. This observation has similarity with the observation in bilogical neurons stimulated external signal.

Synchronization of Randomly Coupled Map Lattices

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A network of chaotic elements is investigated with the use of Globally Coupled Maps, but with different probability coupling among these elements, the effect of random coupling is seen to favor the stronger trend. A lattice with a basis model is introduced, this system falls in a number of clusters exactly equal to the number of different elements in the unit cell (basis). The effect of the random coupling in this case is seen to help the system to be more stable, i.e. few cluster attractors.

Synchronization and Cluster Periodic Solutions in Globally Coupled Maps

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In this work we study the phenomenon of synchronization in a network of nonlinear elements with global couplings. The system we analyze is a family of globally coupled maps (GCM) and for each GCM we find sufficient conditions for synchronization. We focus our attention on the strong coupling limit and show that the dynamics observed in this case holds as we decrease the coupling for a considerable range of values. We also study periodic cluster solutions in terms of low dimensional maps. We prove the existence of period two 2-cluster solutions in some region of parameters and describe their stability both numerically and analytically.

Yang-Lee and Fisher Zeros of Multisite Interaction Ising Models on the Cayley-type Lattices

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A general analytical formula for recurrence relations of multisite interaction Ising models in an external magnetic field on the Cayley-type lattices was derived. Using the theory of complex analytical dynamics on the Riemann sphere, a numerical algorithm to obtain Yang-Lee and Fisher zeros of the models was developed. It was shown that the sets of Yang-Lee and Fisher zeros are almost always fractals, that could be associated with Mandelbrot-like sets on the complex magnetic field and temperature planes respectively.

Robust Synchronization

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Synchronization has its own methods or uses methods of control theory. One of the control methods is the Open-Plus-Closed-Loop(OPCL) method. This method was used to synchronize a Chua dynamics with a prerecorded one. Also OPCL was used for synchronization of continuous and discrete systems. This synchronization is obtained even in conditions of high level of noise. For a chain of neural oscillators (model FitzHugh-Nagumo) the conditions for synchronization are obtained. This method is straightforward and could be adopted for the teaching of the master-slave synchronization.

Electrical Resistance-Emission Spectroscopy of Determining the Electrochemical behavior of Anodized Aluminum Samples in Aqueous Solutions

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An early stage of anodization processes of aluminium samples was investigated in situ by a new non-destructive testing (NDT) method. The new method is based on the optical interferometer for detecting the emission spectroscopy of the electrical resistance of the aluminium samples in sulphuric acid solutions. The observations of the anodization processes were basically interferometric fringe patterns obtained by the 3D-real time-holographic interferometry. The interference patterns were interpreted to electrical resistance-emission spectroscopy in order to determine quantitatively the electrochemical behavior of the aluminium samples during the anodization processes in aqueous solutions. In other words, the new method not only can be used as an 3D-interferometric microscope, with a special resolution in a sub-microscopic scale, but also, the new method can be used for a spectroscopic data acquisition of electrochemical signals of metals in aqueous solutions. Consequently, results of the present work indicate that optical interferometer is very useful techniques as a NDT method for detection the emission spectroscopy of the electrical resistance of metallic samples in aqueous solutions.

Synchronization and Communication using Semiconductor Lasers with Optoelectronic Feedback

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The synchronization of two chaotically oscillating semiconductor lasers with electro-optic feedback is analyzed using the standard rate equations for an individual laser. We calculate the Lyapunov spectrum to show that an individual such laser system will exhibit chaos over a wide range of parameters and that the dimension of the attractor increases linearly with the time delay of the feedback. The lasers are coupled by transmitting a fraction c of the transmitters output power I_T, measuring it with a photo-detector and adding the proportional electric current to the pumping current of the receiver. In the receiver a current corresponding to a fraction (1-c) of its power is fed back, so that the total feedback current of the receiver is proportional to c I_T + (1-c) I_R. We study synchronization as a function of the coupling strength c. When c=0, the lasers are uncoupled. When c=1, the receiver is being run open loop. We show in computer simulation robust synchronization and we also analyze the generalized synchronization of these model lasers when there is parameter mismatch between the transmitter and the receiver.
As an additional tool for investigating the system we build an analog circuit model having a basic frequency of around one kHz, which allows

us to study distortions and search wide parameter spaces much more efficiently than would be possible with a computer and we can at the same time measure quantities which in the experiment with the actual laser system are either inaccessible (population inversion) or hard to obtain (time series). We show synchronization of two of those analog circuit models.

We then address the possibility of communicating information between the transmitter and receiver lasers. We investigate a scheme for modulating information onto the chaotic electric field transmitted between the lasers for a range of couplings c for which synchronization occurs. The feasibility of the communication scheme is demonstrated by calculating the performance curves for a situation where channel noise due to turbulence in air is considered and one where detector noise is taken into account.

Chaotic Phase Locking in Theory and Practice

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We propose a theoretical explanation of the phenomenon of phase synchronization of chaotic systems. Many of the observed characteristics of the phenomenon can be naturally explained within the proposed framework. We test the analytic predictions of the theory in an electric circuit exhibiting a Rössler like chaotic attractor and find good agreement. We conclude that in many instances phase coherent chaotic attractors can be approximated by limit cycles plus a noise term for phase locking calculations. The statistical properties of the noise term give further information about the phase locking.

Chaos Synchronization in Unidirectionally Coupled Maps

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Chaos synchronization in unidirectionally coupled logistic maps is studied. Stability of the synchronous chaotic attractor(SCA) begins to lose when the first perioidc saddle embedded in the SCA becomes unstable transversely. We find two types of transverse bifurcations leading to desynchronization of the SCA: supercritical period-doubling and transcritical contact bifurcation. We will show that depending on the type of the transverse bifurcations, the SCA follows different routes to desynchronization.

Chaos Generator with Frequency Modulation

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Numerical simulation of a chaos generator with frequency modulation is performed. The structure consists of Voltage Controlled Oscillator (VCO) driven by chaotic waveform. Influence of the modulation index value as well as modulation frequency band onto VCO's output signal properties was analyzed. The results obtained can be used in practical design of the microwave chaos generator with desired properties of output signal.

Periodic Orbits and Entropy of Delayed Maps

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We study periodic orbits of general delayed maps and determine how some of their properties vary with the delay value. We relate these properties to the topological entropy and obtain arguments that this entropy, and consequentelly all the metric entropies, is bounded in the high delay limit. The general considerations are exemplified for delayed Bernoulli-like maps and H'enon-like maps.

Initial Condition Estimation from a Scalar Time Series

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We introduce a method to estimate the initial conditions of a mutivariable dynamical system from a scalar signal. The method is based on a dynamical system from a scalar signal. The method is based on a modified multidimensional Newton-Raphson method, which includes the time evolution of the system. The method can estimate initial conditions of periodic and chaotic systems and the required length of scalar signal is very small. Also, the method works even when the conditional Lyapunov exponent is positive. An important application of our method is that synchronization of two chaotic signals using a scalar signal becomes trivial and instantaneous.

Neuron Synchronization Mathematical Phenomenology

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The neuron synchronization has been hypothesized as the basic mechanism leading both neurological phenomena, as the low electroencephalographic rhythm dimension or the high spectral coherence, and cognitive processes as the associative memory. After an analysis of an experiment on cortex periodic photo-stimulation, in resonance conditions, the integrate and fire (I&f) model has been used to simulate the effects of periodical photo-stimulation of the central nervous system (CNS). An extension of the model endowed with Hebbian reinforcement has been applied to the synaptic growth phenomenology. The underlying mechanism, founded on the assumption of a selective augment of excitatory coupling, accompanied by a surplus of synchronization, has been implemented in the i&f model by introducing a firing coincidence counter. The so obtained i&f neural network has been tested to simulate the relationship between rhythm and synaptic growth evolution, the feature binding mechanism and the effects on the CNS of the electromagnetic(EM) field and of the transcranial magnetic stimulation (TMS).

Applications of Chaotic External-Cavity Semiconductor Lasers to Secure Communications

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The synchronization of two chaotic external-cavity semiconductor lasers in a *master-slave* configuration is numerically studied. To synchronize the lasers a small amount of the output power from the master laser (ML) is injected into the slave laser (SL). Under appropriate conditions, we find that the output of the ML can be used as a chaotic carrier to encode a message. Moreover, since the SL synchronization to the ML suppresses the encoded message, this message can be recovered by operating with the input and output of the SL. The quality of the synchronization diagram, when the two lasers are slightly different, is also analyzed.

Detection of Nonlinear Coupling and its Application to Cardiorespiratory Interaction

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We present here a modification of the Lagrangian measures technique, which allows a reliable detection of interdependency among simultaneous measurements of different variables. This method is applied to a simulated multivariate time series and to a bivariate cardiorespiratory signal. By using this methodology, it is possible to reveal a nonlinear interaction among cardiac and respiration rhythms in pathological conditions.

Imperfect phase synchronization

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We demonstrate that the dynamics of phase synchronization in a chaotic system under weak periodic forcing depends crucially on the distribution of intrinsic characteristic times. In systems with nearly isochronous chaotic rotations all motions in the synchronized state are frequency-locked in 1:1 ratio with the driving frequency.
For the Lorenz attractor with its unbounded times of return onto a Poincar\'e surface, such state of perfect phase synchronization is inaccessible.
Analysis with the help of unstable periodic orbits shows that this state is replaced by another one, which we call ``imperfect phase synchronization", and in which we observe alteration of temporal segments, corresponding to different rational values of frequency-lockings.
Stabilization scenarios for periodic orbits are reported, too.

Collective Dynamics of Delay Coupled Oscillators

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We present a detailed analytical and numerical investigation of the effect of time delay on the collective states of coupled limit cycle oscillators that are close to Hopf bifurcation. Time delay is found to have a strong stabilizing influence leading to ``amplitude death'' even in a collection of identical oscillators. It also causes a shrinking of the regions of chaos in the phase space of frequency dispersion and coupling strength. The number of periodic collective states increases as a function of the time delay parameter while the magnitude of the collective frequency gets suppressed. We also present experimental results confirming some of these theoretical findings and discuss their practical implications.

Transition to Chaotic Rotating Waves in Rings of Coupled Chaotic Oscillators

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In this work we study and characterize behaviors occurring in a ring of three unidirectionally coupled chaotic Lorenz systems. Using as reference the synchronized state, the system exhibits a pattern forming instability in which discrete waves arise. Depending on the parameters these structures can have a basic periodic or chaotic waveform. In our work we shall consider the routes connecting these behaviors.

Synchronizing Ergodic Chaos

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Most studies of chaotic synchronization have focused on dissipative chaos. Though less well known, chaotic systems that lack dissipation may also synchronize, and in some applications~(like spread spectrum commnuications) non-dissipative chaos is highly desirable. I will present a family of ergodic mappings on the torus whose synchronous state is globally stable for almost every initial condition. Though extremely unlikely~(measure zero), these systems have trajectories that *never* synchronize. I will give examples of periodic motions that are forever asynchronous in both two and four dimensional systems. Since the total set of these trajectories has measure zero, we do not expect to observe them in experiments using purely random initial conditions. I will also consider the effects of noise in this system. Typically synchronization is disrupted when noise is added, but I will show that a slight modification to the coupling gives robust synchronous even in the presence of noise.

Synchronization of Spatial Chaos in Adaptive Systems

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We have developed a stochastic neural net possessing common features of topology-preserving maps and elastic nets. With no lateral and no elastic synaptic interactions, decreasing the "temperature" (neuronal noise) leads (through a sequence of the phase transitions) to complete disorder, or spatial chaos. The lateral and elastic synaptic interactions can be viewed as weak parametric and weak force perturbations, respectively, stabilizing topological order in the system.

Complex Dynamics of the Pierce Diode

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The chaotic dynamics of a one dimensional plasma filled diode is numerically explored by two different approaches. The first of them is a fluid description and the second one a particle simulation. The system has just one control parameter, namely, the electron transit angle, and presents a complex behavior as a function of it. Once released with given initial conditions the system goes through an initial transient and settles down at some final state. This may be either a d.c. equilibrium, a state exhibiting regular nonlinear oscillations, a chaotic state or a nonlinear oscillation with virtual cathode discharges. These four possible regimes are investigated and the large diversity of patterns observed are reported. The stable and unstable equilibrium solutions and their bifurcations are analyzed. The conditions for virtual cathode formation and consequently the validity of fluid description are verified. In order to characterize chaotic and regular states, the correlation dimension and Lyapunov exponents are been calculated. One of our aims is to verify synchronization of arrays of this spatiotemporal system in regular and chaotic regimes.

Experimental Real Time Phase Synchronization of a Paced Chaotic Plasma Discharge

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Experimental phase synchronization of chaos in a plasma discharge is studied using a phase variable lift technique. Real time observation of synchronized and unsynchronized states is made possible trough a real time stroboscopic sampling procedure. The parameter space regions of synchronization and unsynchronization are identified.

Synchronization and Chaos in a Parametrically and Self Excited System

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We analyze vibrations of a non-linear parametrically and self excited system of two degrees of freedom. Our model contains two van der Pol oscillators coupled by a periodically changing spring of Mathieu type. By means of a multiple scales method the existence and stability of periodic solutions close to main parametric resonances have been investigated. Bifurcations of the system and regions of chaotic solutions have been found. The possibility of hyper-chaos appearance has been also discussed and the example of such solution has been shown.